HAUPT TRUSS BRIDGE
Pennsylvania Railroad
1300 Ninth Avenue,
Railroaders' Memorial Museum
Altoona
Blair County
Pennsylvania

HAER No. PA-207

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WRITTEN HISTORICAL AND DESCRIPTIVE DATA

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HISTORIC AMERICAN ENGINEERING RECORD

HAUPT TRUSS BRIDGE
Pennsylvania Railroad

HAER No. PA-207

Location:	1300 Ninth Avenue, Railroaders Memorial Museum, Altoona, Huntingdon County, Pennsylvania
Date of Construction:	c. 1854
Fabricator:	Pennsylvania Railroad
Present Owner:	Railroaders Memorial Museum
Present Use:	none
Significance:	Designed by Herman Haupt, the Haupt iron truss was a rare combination of Pratt truss and tied arch, constructed and used exclusively by the Pennsylvania Railroad between 1851 and 1861. Haupt's were the first metal-tied arch bridges built in this country, and among the first in the world.
Historian:	Victor Darnell, April, 1986

> This bridge has been pronounced by competent judges to be the most beautiful structure in the world.[1]

This sentence closed the description of the first Haupt iron truss bridge built by the Pennsylvania Railroad at Johnstown, Pennsylvania, in 1851. For ten years the railroad built these bridges at the Altoona shops, the sole developer and only user of the style. It was a good product for the time, carrying trains until locomotives became too heavy, and then roads over tracks, as three still do. Bridge historians, if they mention the design at all, give it only a few lines and ignore the designer. This study attempts to rescue the Haupt iron truss from obscurity by identifying the engineer, tracing the bridge's development and use, and analyzing the design. Photographs and the few survivors, one of which presents an unusual opportunity to examine construction details, have been used to study the structural arrangement.[2]

The Pennsylvania Railroad was chartered April 13, 1846, as Philadelphia competed for the commerce of the trans-Appalachian west. At first, it operated over rented tracks from Philadelphia to Harrisburg. Construction began at Harrisburg and the initial segment, sixty-one miles to Lewistown, opened to traffic September 1, 1849; the next section, seven-six miles to Hollidaysburg, opened September 16, 1850. The eight-five mile western section from Pittsburgh to Big Viaduct, eight miles east of Johnstown, was under construction in 1850; the following year, two sections were in use, twelve miles at Pittsburgh and a longer stretch at Johnstown. The entire western section opened in December, 1852, but the connection between Big Viaduct and Hollidaysburg was delayed by tunnel construction and, until February 15, 1854, the PRR used the state's Portage Railroad at that point. From Philadelphia to Dillerville, near Lancaster, the Pennsylvania operated over the state-owned Philadelphia and Columbia Railroad which it purchased on August 1, 1857. Between Dillerville and Harrisburg, it operated on the tracks of the Harrisburg, Portsmouth, Mountjoy and Lancaster (HPM&L) RR, which it leased on January 1, 1861; before that date, the HPM&L was responsible for the tracks and bridges over which the PRR operated. West of Harrisburg, the railroad was initially single track. The construction of a second track began in 1853, but proceeded slowly because of financial problems; about half the mileage to Pittsburgh was doubletracked by the end of 1855.

The building of the Pennsylvania and the development of iron truss bridges occurred simultaneously. The first iron truss was built for road use in 1840, and the earliest for railroads in

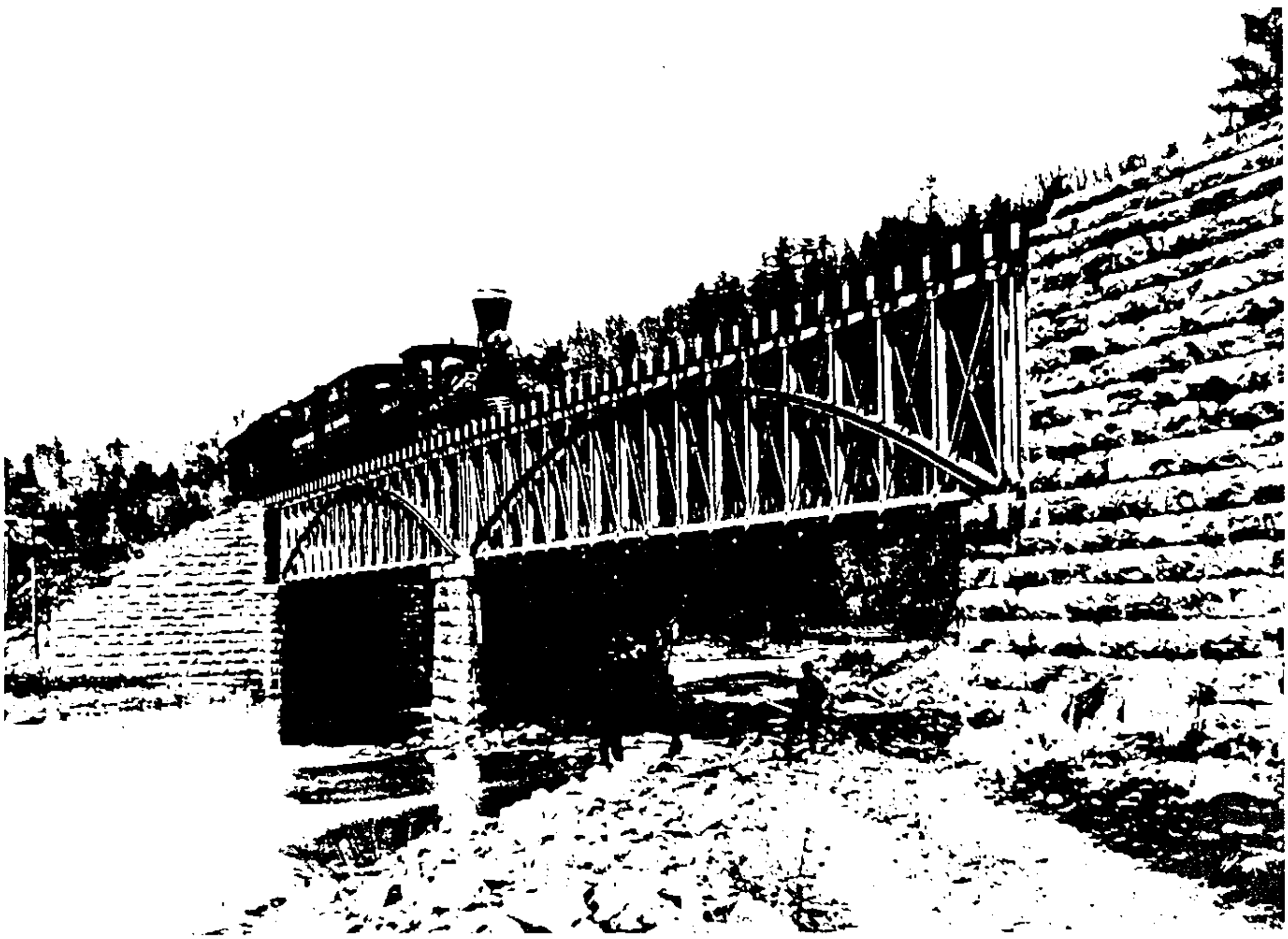

Figure 1
A two-span crossing of the Little Juniata River, c. 1870
National Museum of American History

1845. By 1850, when the PRR extended to Hollidaysburg, railroad trusses had grown from 34' to 91' spans.[3] Timber bridges were less expensive, but iron lessened the danger of fire and reduced maintenance costs. Some railroads, the Philadelphia & Reading and the Baltimore & Ohio, fabricated their trusses, while others bought from bridge builders Nathaniel Rider and Squire Whipple. Several iron designs came directly from wood or composite examples; others, such as Whipple's trapezoidal type, were new. Combinations of timber arches and trusses had been built for some time, but the division of the load between the two elements, or the designer's intent that one be the primary element, is not clear. Thus, one structure could be a truss reinforced with an arch while another an arch stiffened by a truss. In the absence of evidence of the designer's intent, both arrangements are usually described, sometimes wrongly, as trusses with arch reinforcing. In a few instances the thrust of the arch was carried by the structure, a tied arch, instead of by the abutments.[4] Although the final Haupt design was an arch stiffened by a truss, it has commonly been labeled a truss because that element was more noticeable; I have followed that convention.

Although not named specifically as the designer, the evidence suggests Herman Haupt was likely responsible. Edward Miller (1811-1872) was the engineer for the section where the first iron example was erected, and succeeded Haupt as PRR's chief engineer; however, Miller's obituary, which described his professional activities, did not mention any bridge construction while he was with the PRR. J. Edgar Thomson (1808-1874) was responsible for construction when the truss was developed, but he is an improbable candidate, given the variety and number of his other tasks and his evident lack of interest in this sort of activity. Herman Haupt (1817-1905), on the other hand, was involved in bridge construction from 1835 until he left the Pennsylvania Railroad in 1856. A few months after graduating the U.S. Military Academy (in 1835) he resigned from the Army and began to work on railroad construction. Patent No. 1445, awarded to Haupt on December 27, 1839, covered a timber truss. Subsequently, he studied bridge design and, from 1844 to 1846, worked on his book General Theory of Bridge Construction..., first published in 1851. In late 1847, he started working for the PRR as a surveyor and, the following spring, J. Edgar Thomson made him assistant to the chief engineer, with a further promotion to superintendent of transportation in February, 1849. After his first promotion, Haupt assumed responsibility for the bridge across the Susquehanna at Rockville, where Daniel Stone built the twenty-three 180'-long Howe trusses. Haupt left the railroad in September, 1852 but returned after a few months as chief

CANAL BRIDGE.

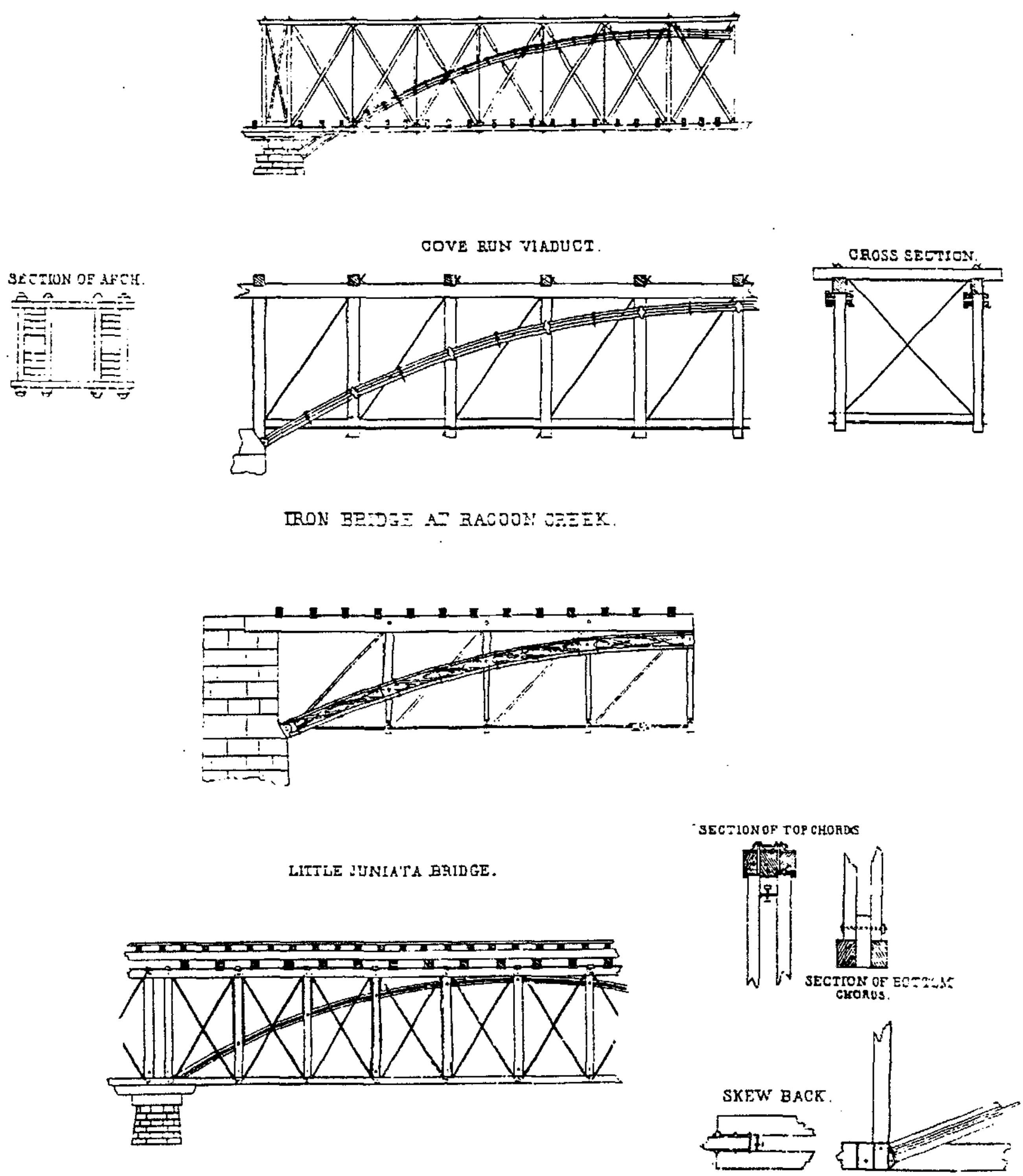

Figure 2
Experimental structures
Assembled from plates in Haupt's book

engineer. By April, 1855, he was spending only a third of his time on PRR business, and severed his connection with the railroad about the end of 1856. His later career included work on the Hoosac Tunnel, oil pipelineconstruction, a brief stint directing military railroads, and general management of the Northern Pacific RR. Haupt's early career and his position with the PRR suggest that he was responsible for the PRR's first iron bridges and that the style should, indeed, be called the Haupt truss. It has been nameless until now, because the inventor went on to other projects and did not advertise his design as did other bridge promoters.[5]

Haupt's book and the Johnstown bridge both appeared in 1851. While Haupt described more than a dozen railroad bridges, five related to the development of his design. The first was the 23-span timber bridge over the Susquehanna River. He calculated the bridge's strength under three assumptions - the truss carried the whole load, or the arch did so, or the arch and truss together formed one system - and described how adjusting the iron rods connecting them would determine which applied. The other four designs were for experimental structures, three of which were built in the section just west of Harrisburg.[6] The bridges were described in geographical sequence from east to west, but this may not have been the order in which the designs were made. The descriptions are based on Haupt's book from which the profiles of Figure 2 were taken.

The Canal Bridge was a 133' span combining an iron arch with a Howe truss. The arch was placed on the truss's centerline and consisted of a cast-iron I-section with two wrought-iron plates on each flange. Loads were applied to the arch by jacking screws in the counterbraces and below short struts to the top chord, all in the same plane. The arch continued through the bottom chord to the abutments. Haupt used the jacking screws to experiment with the iron arch's strength and concluded that an iron counterbraced arch was practical, but that iron tie-rods should not be used for the bracing truss's bottom chord because of expansion and contraction from temperature changes.

The design for a 50' span at Cove Run was not used. Each side consisted of a pair of iron arches stiffened by a composite truss between them. Each arch was made of eight 2" x 3/4" bars with spacers between the upper and lower groups of four bars. It was to have been a deck bridge with the truss posts taking the load to the arches. The 47' span at Racoon (sic) Creek was similar, but the posts of the bracing truss were changed to cast iron and each arch consisted of six 3" x 1" bars with spacers between the upper and lower groups of three. In both designs only the arch carried the load, for the trussing was only bracing. They differed from the Canal Bridge where either the arch or the truss could support the entire load.

The fourth bridge, the 60' span at Little Juniata, led directly to the final all-iron design. The truss was a Pratt type with three timbers abreast for the top chord, web posts under the outer ones, and the web roads passing between the three. The arch was under the middle timber, and load was applied to it by posts in that plane. It was made of two wrought-iron U-shaped rails, one over the other with seats separated by cruciform-shaped cast-iron bars. The truss bottom chord also functioned as the tie for the arch; it was two full-length timbers, one on either side of the arch. Haupt wrote that "(i)ts main peculiarity consists chiefly in the manner of constructing the arches and the arrangement of the details." It appears that this "peculiarity" made him revert to the Canal Bridge's safety feature of a full-strength truss in case the arch proved inadequate. His views of the arch tie/bottom chord were somewhat ambivalent. If the structure carried the rails at the top chord level, the arch tie needed to resist only the dead load, for the live load could be carried by the wedges to abutments or adjoining spans. But if the rails were at the bottom chord - that is, resting on the top of the piers or abutments - the tie would have to carry the dead plus the live load. It was safer to design the structure to be completely self-supporting with no reliance on wedging.

In the absence of construction dates, it is not known if the structures were built in the order presented. However, there appears to be a progression - from the experiments at Rockville, where an iron arch was incorporated into a dual structural system and tested; to the iron arches with bracing trusses at Cove Run and Racoon (sic) Creek; to construction details with a tied arch at Little Juniata; and, finally, to the all-iron spans.

From these experiments came "the most beautiful bridge in the world," fabricated at Altoona and erected at Johnstown in 1851.[7] It carried a single track for 380' on five spans each, 73' long with 1'-6" extensions at both ends. One of the trusses, depicted in Figure 3, resembled other Haupt spans except that it used two different panel lengths and omitted counter diagonals in the end panels. For some years, this structure was the only section of single track on the main line west of Altoona; during 1868-69, it was replaced by a new structure. Eight of the trusses were used in a bridge over the Juniata River on the Tyrone branch, and some of the Johnstown bridge, either the other two trusses or parts from the Tyrone branch relocation, were later used at Jeannette to carry one of the streets over the tracks.

The typical Haupt iron truss had a cast-iron top chord shaped like a bridge rail or inverted U; cast-iron I-section web posts; and two rectangular-section cast-iron arches. Wrought iron was used for the round rods of the web diagonals and the bars of the bottom chord; fabricated at Altoona,[8] they either replaced timber trusses or were installed as track was doubled. It is not known how many were built, but photographs exist of at least fifteen bridges; all are multiple spans using from two to six identical trusses. Most carried the track on the top chord, but at least two had the track slightly above mid-height of the trusses. Lengths of trusses ranged from 65′ to 110′, probably overall dimensions rather than engineer's design length. Their locations stretched from Whitford, seventy-five miles east of Harrisburg, to Johnstown, a total distance of 250 miles; but there may have been none on the section leased from the HPM&L, as that lease began the same year that the last Haupt truss was fabricated.

Jacob Linville, who became the railroad's engineer of bridges and buildings in 1858, did not approve of cast iron for the truss's top chord, finding that its shape precluded increasing the size of the web rods; by 1861, he had convinced J. Edgar Thomson to use other designs. However, the Haupt type appeared again in the Connecting Railroad's 262′ Schuylkill River bridge, built in 1865. Thomson insisted that Linville add arches to his design, but they were purely cosmetic, carrying no load.[9] By 1869, some of the Haupt trusses had to be replaced; others were strengthened by replacing wrought-iron rods with steel; or the span was reinforced by doubling up trusses to two per side. The effort to strengthen the bridges by substituting steel rods or the cosmetic addition to the Connecting Railroad bridge shows that the basic structure of Haupt's design was not understood by his successors. This is also true for the survivors at Ardmore and Villanova, but these now carry ordinary road traffic and not locomotives. Not all trusses were scrapped, for the PRR used them on less travelled tracks or to carry highway roads over tracks. Three of these crossings remain, and three more were removed only recently.[10]

Costs for materials and erecting Haupt trusses varied widely. An estimate of materials for one span of the Johnstown bridge, with assumptions regarding bracing members and details, indicates that it required 19 tons of cast iron, 11 tons of wrought-iron bars and rods, and 0.4 ton of wrought-iron nuts. Using cost data from Haupt's book, this 76′ span cost about $2,500 for erection, painting and the timber cross beam and stringers but excluding

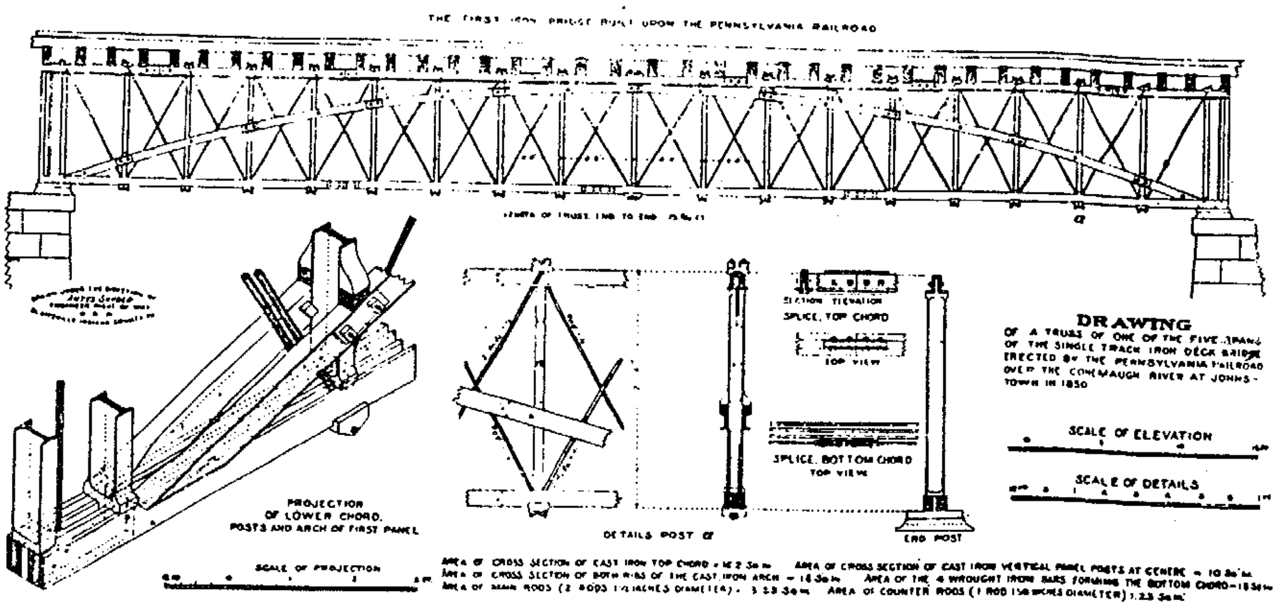

Figure 3
The 1851 Johnstown bridge
From Watkins, History of the Pennsylvania Railroad
National Museum of American History

the rails. This was nearly $33.00 per foot, as opposed to others that Haupt presented: $21.94 per foot for the 60' Little Juniata crossing discussed earlier, and $20.08 per foot for the 160' timber spans over the Susquehanna River at Rockville.

Descriptions that follow are based on viewing the three bridges in service;[11] close examination of the Altoona material; descriptions by Dredge and Watkins; and photographs and card stereographs. Dimensions of components were obtained in Altoona.

In surviving bridges and photographs, Haupt trusses had fourteen, sixteen, or eighteen panels of equal length within a truss. Usually, the endpost bore on the bottom chord with the arch's extrados ending in the corner that they formed. Truss length is the distance between the centers of these endposts, and depth is out-to-out of the chords, excluding the connection castings. Ronks is a fourteen panel truss, 63' long and about 7'-7" deep. Ardmore and Villanova are duplicates of fourteen panels, 70' long and 8' deep. Dredge wrote that truss lengths ranged from 65' to 110'; these were probably overall lengths and the engineering lengths, which the writer uses, would then range from 63' to 106'. Within these limits, the following proportions were reasonable:

Table I

	Truss Length	Depth	Panel Length
14 panels	63' to 75'	8'	4'-6" to 5'- 4"
16 panels	75' to 90'	9'	4'-8" to 5'- 8"
18 panels	90' to 106'	10'	5'-0" to 5'-10"

Panel lengths approximate the 5' desirable for two cross timbers. Depth/length ratios of 1:9 to 1:10 are normal for the spans, although Ronks is shallower. Table I is a guide to the lengths of bridges in photographs. As bridges at Altoona and Ronks suggest, the PRR did not have standard lengths to simplify fabrication.

There is no evidence concerning the lateral spacing of trusses. Those of a single-track bridge were probably about 8' apart. Three trusses were used for structures carrying two tracks; if tracks were midway between trusses, that on the centerline carried twice the live load of the side trusses when the span carried two trains. However, moving tracks outward to the third points equalized loads on the three trusses. The tracks of the Mt. Union bridge, 1871, were so placed, and photographs indicate that this method was used to balance loads on the Haupt bridges. If, as in Figure 4 below, tracks were 12'-2", center-to-center, trusses would be 9'-2" on centers, a reasonable distance.[12] Photographs and details of the Altoona truss indicate spacing of half-through trusses at about 10'-6" and track placement at halfway between trusses. It is not known if the center truss of a double track half-through structure was of heavier material because it carried two tracks, or if trains were scheduled so as to avoid loading both tracks simultaneously.

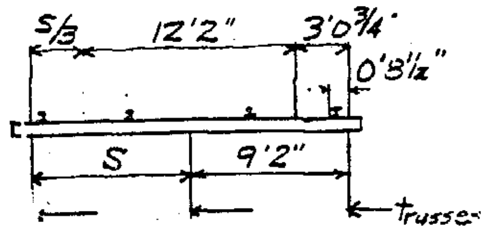

Figure 4
Lateral spacing of trusses

The top chord was a cast-iron section variously described as bridge rail, inverted-U, or hat. Profiles of Ardmore/Villanova are the same as Altoona's except that the crown is thinner. The brim projections at Williams Grove must have been less, with swellings at the holes for the web diagonals providing sufficient edge distance. Small projections on the top of the crown received horizontal forces from the joint blocks, and there were annular bosses on the top of the brim around the holes for the main web diagonals. Interior chord segments were two panels long with splices at mid-panel; end sections were spliced in the first or second panel and extended past the endpost to support the transverse timber. Slice bars were asymmetrical I-shaped castings projecting above and below the chord; the top flange of the "I" extended about 1/2" beyond the slot in the main member. Two horizontal bolts secured the end of each chord section to the splice, and the ends of these pieces seem to be "as cast," not faced to obtain even bearing or exact length. Some bridges had two sets of web holes near the ends of the top chord. Their spacing differed from that of the splice holes, and their purpose is not known, although one is used for the auxiliary endpost. Haupt advocated joining the top chords of timber trusses over intermediate piers, and this may have been carried over to the iron design. One of the road-carrying bridges had the holes at only one end and another had none; the former may have been originally an end span, the other a later design development or a single span crossing. If the top chords had been spliced at the piers, wedges might have been driven at the ends of the bottom chords, but all signs of this would have disappeared when the bridges were taken down.

The cast-iron arch was a circular segment with as much rise as possible. It consisted of two nesting segments, each with pieces two panels long spliced alternately at the web posts where bolts stradding the post connected the two arches of each truss. The abutment casting was the most complicated of the whole structure--it took the place of one segment at the first interior panel, provided bearing for the other at the top of the bottom chord, and then thickened and twisted laterally to go between the outer pair of chord bars where long horizontal bolts grasped the two abutment castings and four chord bars. The ends of the arch segments were unfinished, as were those of the top chord.

The bottom chord consisted of four parallel wrought-iron bars, each made of pieces four panels long with joints staggered such that only one bar was spliced in a panel. Splices consisted of two plates connected by rivets, but there were no splices in the end panels, the bottom chord member being extended beyond the usual four panel length. The shear connection between the bottom chord and the joint casting could be examined only at Altoona, but it was undoubtedly the same for all Haupt trusses. At alternate panel points, there were 1/2" x 1-3/4" notches in the lower edges of the two inner or the two outer bars; these fitted over 1/4" projections of the joint castings. This connection, like that of the top chord, was very weak and will be discussed below.

Web posts were cast-iron T-sections whose webs thickened near the ends to form rectangular sections; depth was constant while flanges increased in width from ends to mid-length. At the top of the posts, a small lug fit into the top chord, while at the bottom there were small projections that went between the chord bars; those of the endpost went into recesses in the arch abutment castings. Except at this last spot, where web posts could move several inches from their proper locations, only web diagonals limited movement. Recesses in the thickened ends allowed for vertical bracing fastened with a bolt. Ronks is an exception to this detail; the bracing was attached between pairs of ears that projected near the top and bottom of alternate posts. The upper connection for the bracing at Altoona, built as a half-through bridge, is in the bracket that supported a longitudinal timber; at this spot, the web of the post is thickened and there is a hole to attach the timber. A bridge at Summer Hill, and that shown in Figure 4, had large circular holes in the webs of the posts; other structural differences that

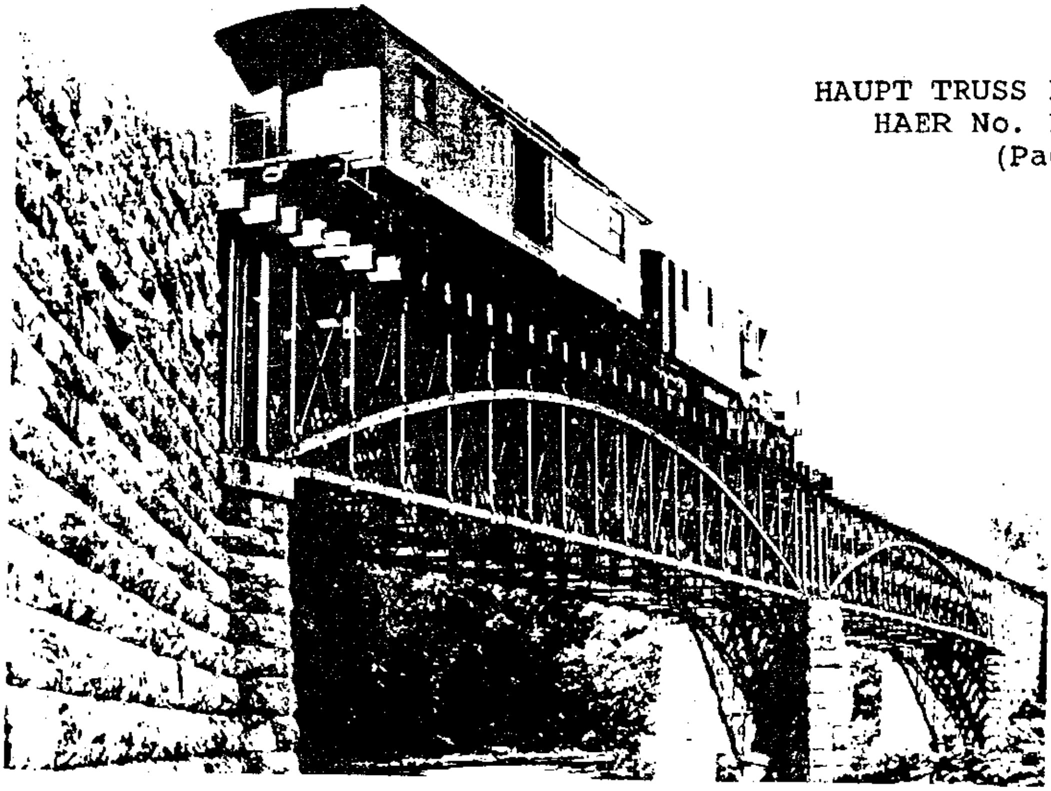

Figure 5
A Bridge over the Juniata. Note the location of the endposts and holes in web posts.
Purviance stereograph no. 263, c. 1870.
Private collection

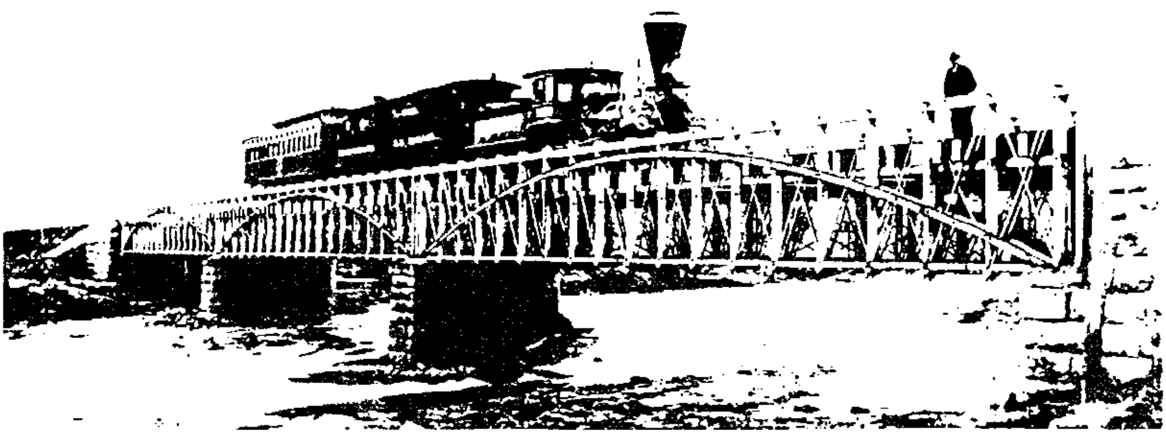

Figure 6
A half-through truss, location unknown, but similar to Vandevanders, with a photographers special train. c. 1870.
National Museum of American History

indicate that these were early Haupt spans.[13]Web diagonals were round wrought-iron rods with threaded ends. The ends were not upset for the threads and this wasted about 20 percent of the material in the body. At Johnstown, all the main rods were the same size; At Altoona, they ranged from 1-1/2" to 1-3/4". The extent to which these rods were tightened controlled the shape of the truss and the sharing of load between truss and arch. Improper adjustment could distort a truss, turning the space bounded by the chords and web posts into a parallelogram; posts would no longer be square with chords and would have eccentric loading and poor bearing. Tops of the web posts at Altoona are about 1" out of proper location. The tightening of the rods also affected the truss's camber - that of Altoona's 99' truss, measured with the truss lying on it side, is 5".

Truss connections were cast-iron blocks bearing on the outsides of the chords. Those of each chord were alike, except for those at midspan, with sloping surfaces giving flat bearing to the diagonal rods. Top-chord blocks had projections straddling the chord's crown, but lacked means of connecting horizontal bracing. Castings at the bottom chord had small projects that fit on either side of the bars and the two 1/4" projections already mentioned, transmitting horizontal forces from the web diagonals to the bottom chord. Alternate castings had projections with double holds to connect the bracing. All holes for the main rods were identical at Altoona, even though rod sizes varied; the out part seemed to have ben drilled and the remainder cored in the casting.

A large cast-iron sole plate transferred the load from the truss to the masonry below. It also provided connections for the bottom chord bracing, end counter diagonal, and a rod to the top chord outside the endpost. At the abutment end of the Altoona truss, it is almost 6" longer than the other and has an additional vertical hole which might have been used for an anchor bolt. The difference in sole plate length and bottom chords that extended to their ends may be the only way to identify the original location of a truss in a multiple span crossing. The sole plates probably rested on cast-iron masonry plates; there is one at Villanova. It is doubtful that expansion rollers were used between the sole and masonry plates.

At the abutment end of the truss, an auxiliary post supported the load of a cross timber next to the abutment and resting on the overhanging end of the top chord. Altoona's is about 1' 6" from the main endpost and was similar to the other web posts except the top projection was longer to allow bolting to the top chord. The usual projections at the bottom fit into recesses in the arch

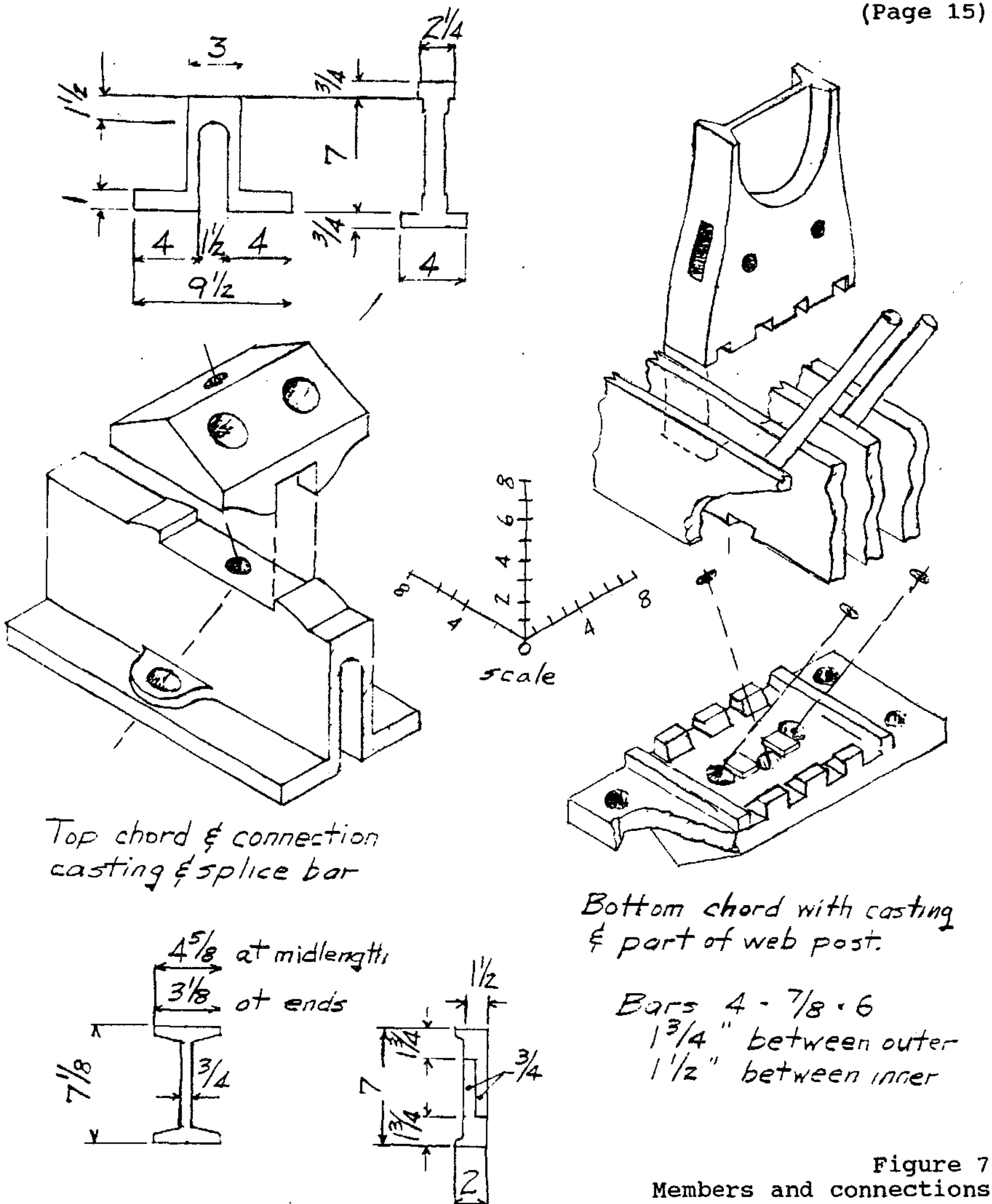

Figure 7
Members and connections
Altoona truss
(Victor C. Darnell)

abutment castings. At the intermediate piers, another auxiliary post was supported on the ends of both trusses that were butted together. The variant Summer Hill bridge had two auxiliary posts at the piers. At each end of the trusses, there was a vertical rod between the main and auxiliary endposts with nuts above the top chord and below the sole plate; this held the chords together and kept the posts from slipping out of place.

Rails were supported by 5" x 12" white oak stringers that rested on 7 x 14 white pine cross beams. Two beams in each panel length, located at the quarter points, were supported by the top chord, or longitudinal timbers on the half-through structures. Cross beams of deck trusses were probably secured to the top chord by J bolts, as there were no holes in the chords for direct attaching.

Nothing remains of the bracing, which was discarded when the bridges were converted to highway use, but photographs and connection holes offer some evidence. Vertical bracing at alternate panels (beginning at truss ends) was made of round rods, flattened at one end to fit into the recesses of the web posts, and threaded at the other to connect to a ring halfway between trusses. The bottom chord system consisted of struts at the same panels as the vertical bracing and diagonal "Xs" of rods. The strut probably was a cast-iron inverted "T" connecting to the two holes in the truss-connection casting. The diagonal rods may have picked up the same holes with a clevis or, more likely, connected to the stem of the "T" and at mid-length fastened to a ring. The holes in the Altoona connection castings range from 7/8" to 1-3/8", suggesting that the bracing was designed as a horizontal truss to resist lateral loads. The struts of the bridge shown in Figure 4 and of Summer Hill clamped to the bottom chord close to the panel points; jaws show above and below the outside bar. The upper level of bracing is all conjecture; Dredge mentioned it and it was necessary for the stability of the bridge, but there are no connection holes or indications of how the members fastened to the trusses. The writer suggests that the arrangement and sections used at the bottom chord were repeated, and the "T" strut was fastened to the chord by means of J-bolts. The Altoona truss offers no direct evidence of connections for the upper level of bracing. However, track support brackets that also provided for vertical bracing have signs of a horizontal extension that has broken off; the bracing strut could have bolted to this, as it did to the bottom-chord connection castings.

Quite a few of the bridges were skewed, for the railroad ran along the rivers and had to cross them as they twisted through the mountains. With the small panel length, web posts might be kept opposite each other, and the basic pattern used, although it would be complicated at the ends of the trusses. If this were not possible, then the complications of offset holes in the struts and bends in the rods would be necessary.

Haupt's iron truss was a practical success, carrying trains for a number of years and then carrying lesser loads for more than a century. But even more, an engineering review of truss members and their stresses suggests that the Haupt iron truss bridge was a successful pioneering effort that adequately carried the loads for which it was designed.

In appearance it was a combination of structural systems, a Pratt-style truss and a tied arch. The combination was not a bad idea for timber trusses where one system could carry the dead load while decayed members of the other were being replaced, but this is not the situation in metal structures. When Haupt was designing his bridges he did not have the design methods or information on materials that we take for granted now. He was perfectly aware that in a compound system of arch plus truss the load carried by each depended upon their relative flexibility, but, as procedures for calculating deflections were not available until much later, he wisely depended upon one structural system to carry the load with the other provided for stiffening. The allowable compressive strengh for cast iron was fairly well established when these bridges were designed. The allowable tensile stress for wrought iron was not. Squire Whipple recommended a maximum of 10,000 puonds per square inch, bot Vose used 15,000 pounds per square inch and ignored the loss of area that resulted from cutting threads in rods; Haupt called for a limit of 8,000 to 10,000 pounds per square inch and did not mention if it applied to gross or net area. Whipple and Haupt both used a live load of 2,000 pounds per linear foot of track.[14]

The writer has analyzed the first bridge which was erected at Johnstown and the one erected at Vandevander, now at Altoona, using Haupt's live load of 2,000 pounds per foot of track. The Johnstown bridge carried a single track. The tied arch structure was adequate when carrying the entire load, dead and live, although the arch tie was over-stressed by about seven percent. When the truss was considered to carry the entire load, the members were adequate except for some of the web rods which were severely overloaded. The worst had a stress on the body of the rod of 14,400 pounds per square inch, and where the threads reduced the area it increased to 20,500 pounds per square inch; the first was far above Haupt's recommendation, and the second was about at the material's elastic limit. Assuming that the connections were similar to the material at Altoona, those which transferred the horizontal forces from the web diagonals to the chores were severely overloaded at the top chord, and the 1/4" projections of the bottom chord castings were theoretically loaded to the point of failure. Actually, parts of these connection loads wwould have been transferred by friction between the castings and the chords, but this cannot be considered in design because of its uncertainty. The truss was stiffer than the arch and, if both could behave elastically nder the maximum load, the truss would have carried 63.4 percent of the total load. The loads in some of the truss web rods and in the connections were above the elastic limit so that, while the truss could support part of the load, it was secondary to the arch. Analysis of the Vandevander bridge with only one track loaded gave the same results except that the arch tie was 23 percent above Haupt's recommended limit (this stress of 12,300 pounds per square inch would not bother later engineers), and the truss connections were mathematically even more overloaded. While the trusses could not carry much of the load imposed by locomotives, they have been adequate for road traffic.

Dredge wrote that the arch was an added precaution, and Linville wrote that he had strengthened some of the bridges by replacing the wrought-iron web rods with steel members.[15] Their actions occurred when Haupt had gone on to other activities but, as he had written, "These and many other considerations have led the writer to the conclusion that the best method of constructing bridges is to place the entire dependence upon the arch, using the truss merely as a system of counter-bracing and a support to the roadway."[16] The writer's analysis indicates that the Pennsylvania Railroad bridges were tied arches and that they were properly designed for the loads of their period. The inadequacy of the truss connections reflects the experimental nature of the early iron structures, as does the overloading of the diagonal rods. Since the truss was a bracing member, not the primary load-carrying system, the overall design was very good.

The writer believes that Herman Haupt originated this design from his experiments made on the Pennsylvania Railroad and his study of bridge construction. There is a logical path of development from the Canal Bridge through that at Racoon (sic) Creek to the tied arch at Little Juniata and finally to the all-metal bridge at Johnstown. The bridges are the first metal-tied arches built in this country and were among the earliest built in any country. George Vose's comment, made in connection with Haupt's earlier timber truss, applies here as well: "The name of the builder is sufficient to warrant the ability of the bridge."[17]

It is hoped that the survivor at Ronks will be preserved when taken out of service. It is not large and could be moved on one piece to the Railroad Museum of Pennsylvania, only a few miles awat. It is one of the oldest metal bridges in this country and displays the engineering and metalworking skills of the pre-Civil War era in a manner far superior to words or drawings or photographs.

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ENDNOTES

1. Johnstown (Pa.) Mountain Echo, as quoted in American Railroad Journal, September 13, 1851, p. 585.

2. The Railroaders' Memorial Museum, Altoona, PA, has one truss and the wreckage of another that carried Route 333 over the tracks at Thompsontown, PA, until late 1983 or early 1984. The second truss broke while being taken down, and the pieces reveal details that are hidden in an assembled truss. Watkins (p. 29) wrote that iron trusses from Vandevander's bridge were used in 1889 for an overhead bridge at Thompsontown. A letter from Willis Van Devanter to the writer, January 13, 1986, stated that Vandevander was named after a direct ancestor and was near Mapleton, about nine miles east of Huntingdon.

3. The first iron railroad bridge was the 34' span built by the Philadelphia & Reading Railroad and erected at Manayunk on May 3-4, 1845; one truss is preserved at the Smithsonian Institution. The 91' trusses were built in 1850 for the Virginia Central Railroad over the Rivanna River by the New York Iron Bridge Company, successor to the Rider Iron Bridge Company.

4. See plates XIII, XIV "New York and Erie Railroad, Bridge over the Lackawaxen River and Delaware and Hudson Canals," in George Duggan, Specimens of the Stone, Iron and Wood Structures...of the United States Railroads (New York: D. Appleton and Co., 1850.)

5. Miller's obituary appeared in U.S. Railroad and Mining Register on April 27, 1872. The lives of Thomson and Haupt are covered in books by James A. Ward. Professor Ward, in a letter to the writer on January 3, 1986, indicated his agreement with the writer's attribution of design.

6. The Canal Bridge was located at Rockville, just east of the Susquehanna River and Stone's long timber crossing. Cove Run was about five miles to the west. Raccoon Creek is opposite Millerstown, about twenty-eight miles west of Rockville. The Little Juniata Bridge could have crossed a creek near Duncannon, between Millerstown and Cove Run, or the Little Juniata River, which begins about seventy miles west of Millerstown. Watkins (p. 7) implied that the structure crossed the river, but the writer thinks it was over the creek, as this would place all four in the same general area and construction phase.

7. When Antes Snyder made the drawing (Figure 3) for Watkins' history, he gave the construction date as 1850. Dredge and Watkins, both of whom had access to the railroad's records, gave 1851, which seems to be confirmed by the American Railroad

Journal which would not have waited one year to describe a new kind of iron bridge. Snyder used 1850 in his presentation to the Engineering Society of Western Pennsylvania [Proceedings, XVIII (1902) 433] and L. N. Edwards has repeated it in A Record of History and Evolution of Early American Bridges (Orono: University Press, 1959), p. 192.

8. Bridges were fabricated at Altoona into the mid-1860s. Among them was the 320' span for Steubenville, the first of this country's long span trusses.

9. Linville's comments appeared in his undated letter to A. P. Boller, printed in the discussion of J. E. Greiner, "The American Railroad Viaduct...," ASCE Transactions XXV, 1891, p. 366.

10. The survivors are all single spans over the mainline tracks. The one at Church Road, Ardmore, did not have the arches re-erected. Spring Mill Road, Villanova, has most of the arch segments. Ronks is complete and provides access to a farmer's fields. The one at Gap was replaced by a new bridge during 1984. Another had spanned a single track at Williams Grove/Mechanicsburg, but the writer could not find it in 1984. The third is ex-Thompsontown, now at Altoona. Except for the last, they originally were deck trusses, but when converted, all six carried the road at the bottom chord level.

11. Cross-electrified tracks and corrugated metal on the sides of the trusses makes examination or measuring almost impossible.

12. Burgess and Kennedy (p. 85) stated that the PRR used 12'- 2" track spacing west of Harrisburg. The HPM&L used a smaller spacing which caused operational problems.

13. Summer Hill is shown on stereograph card no. 453 by W. T. Purviance of Philadelphia.

14. Squire Whipple, Bridge Building... (New York: D. Van Nostrand, 1869), p. 45; Vose, pp. 129, 145-6; and Haupt, p. 165. For live load, see Haupt, pp. 115 and 175.

15. Dredge, p. 54, and Linville (note no. 9 above), p. 366.

16. Haupt, p. 175.

17. Vose, P. 173.

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